§7. Development of Fine-Grained, Particle-Dispersed Vanadium Alloys with Improved Resistances to High-Temperature Deformation and Embrittlement by Neutron and Helium Irradiations

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A V-4Cr-4Ti alloy with reduced contents of solute oxygen and nitrogen processed by electron-beam melting is a primary candidate material for fusion reactor structural applications [1, 2]. In order to make the alloy more attractive, it is necessary to improve both the resistance to embrittlement by neutron and helium irradiations and strength at high temperatures. So far, the authors showed that the microstructure of fine grains and fine dispersoids of Y_2O_3 and YN, which are produced by powder metallurgical methods including mechanical alloying (MA)[3~6] is very effective in improving the resistance to radiation embrittlement in vanadium. They also studied the high temperature deformation of V-(1.7-2.4) mass% Y alloys and showed that grain boundary sliding occurs significantly above 1100K and the resultant strength loss cannot be compensated by dispersion hardening by Y_2O_3 and YN particles[7]. This indicates that suppression of grain boundary sliding is required to improve the high temperature strength of V-(1.7-2.4) mass% Y alloys above 1100K.

Addition of Ti to vanadium causes solution hardening and is expected to suppress grain boundary sliding by changing grain boundary chemistry and/or structures. In this paper, the effect of Ti addition on microstructures and high temperature behavior of fine-grained, particle dispersed V-1.7mass%Y alloy is examined, aiming at finding a way for suppressing grain boundary sliding above 1100K.

Powders of pure vanadium (particle size: <150μm, oxygen: 0.08%, nitrogen: 0.07%, in mass%), pure yttrium (<750μm, 1.56%, 0.05%) and Ti (78μm, 0.35%, 0.02%) were used as the starting materials. They were mixed to provide the nominal compositions of V-1.7%Y-2.1%Ti and V-1.7%Y in a glove box filled with purified Ar gas (purity 99.99999%). Each of the mixed powders and WC/Co balls was charged into two WC/Co milling vessels having an inside volume of 250cc. The vessels sealed with oxygen-free copper gasket were taken out of the glove box and set to a planetary ball milling apparatus for MA.

Each of TIG sealed mild steel capsules containing MA processed powder was subjected to. HIP at 1273K and 200MPa for 3h. The as-HIPed compacts had the density of 6.08 g/cm^3, approximately 99.7 % of theoretical. From the as-HIPed compacts, specimens for microstructural observations, X-ray diffraction analysis and tensile tests were prepared. The dimensions of the tensile specimens are 16mm x 4mm x 0.5mm with the gauge section of 5mm x 1.2mm x 0.5mm. All of the specimens were wrapped with Ta foil and then Zr foil and annealed for 3.6ks at 1273 K for V-1.7%Y-2.1%Ti and 1373K for V-1.7%Y in a vacuum better than 5 x 10^{-5}Pa. Tensile tests were performed at temperatures from 873 to 1273K at an initial strain rate of 1 x 10^{-3} s^{-1} in a vacuum better than 3 x 10^{-4} Pa. Ta and Zr foils having the dimensions identical to the tensile specimens and being separable into two parts were placed in contact with the specimens to suppress pick-up of gaseous interstitial impurities from the surrounding during the test. Microstructural examinations were made by transmission electron microscopy (TEM) with JEM-2000FX operating at 200kV. The main results are as follows.

1) Comparison of microstructural parameters between V-1.7Y-2.1Ti and V-1.7Y alloys (table 1) shows that V-1.7Y-2.1Ti has larger grain size and lower particle density than V-1.7Y in spite of lower annealing temperature.

2) The amount of 1% Ti is in solution in V-1.7Y-2.1Ti and the remainder exists as the constituent of large dispersoid of $Y_2Ti_2O_7$.

Table 1 Microstructural parameters in two alloys developed.

	Grain diameter (nm)	Particle density ($10^{20}/m^3$)	Particle diameter (nm)
V-1.7Y-2.1Ti	518	6.0	14.7
V-1.7Y	339	31.3	12.9

3) The yield stress for V-1.7Y-2.1Ti is considerably higher than that estimated from the grain size dependence of yield stress for V-(1.7-2.4)Y alloys [7]. In particular, at 1273K where V-(1.7-2.4)Y alloys exhibit no grain size dependence of yield stress due to significant grain boundary sliding, V-1.7Y-2.1Ti shows that appreciable grain size dependence of yield stress, indicating the occurrence of suppression of grain boundary sliding even at 1273K.

4) In view of both less contribution of dispersion hardening to high temperature strength in V-1.7Y-2.1Ti due to less particle density and the presence of 1% solute Ti, the observed high strength at 1273K is most likely due to solution hardening by Ti. This indicates that solution hardening is very effective in suppressing grain boundary sliding in fine-grained, particle dispersed V-1.7Y alloy. It is thus expected that larger amounts of Ti addition may lead to further improvement in high temperature strength.

Reference

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